91602
new 82-10

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

ontario hydro
research division

To: Mr. J.E. Mitchell
Manager
Tech Services & Development
Program Support & Services Division

Transient Measurements in a Residential Environment

G.K. Hatanaka

Residential transients associated with the local switching of common household equipment were captured on a Nicolet 460 digital oscilloscope. Line-to-neutral disturbances were measured with modest amplitudes of less than 120 volts. Switching a freezer on and off generated fast transients, characterized by bursts of impulses lasting about 20 μs with individual impulse risetimes of 20 ns or less. The individual pulses are closely spaced with repetition rates of up to 8 MHz. Problems were experienced with the BMI 4800 power line disturbance monitor. The BMI recorded levels up to 30 times higher than the Nicolet during simultaneous measurements. The BMI also exhibited large inconsistencies between individual channels that varied with the instrument settings.

1.0 Introduction

Many equipment problems being experienced by customers result from the incompatibility between the quality of power existing at the point of utilization and the power requirements of the utilization equipment. Power line disturbances are an unavoidable adjunct to the supply and use of electric power. Problems will occur if the disturbance levels exceed the equipment tolerance levels. The solution to these problems is to provide equipment with adequate tolerance levels or to provide suitable protective equipment. Before these equipment requirements can be established we need to know the severity of the disturbances at the customer facility. Research Report 91-163-K [1] describes the results of a general power quality measurement survey performed at a limited number of typical industrial sites.

As part of this general goal of characterizing power line disturbances at customer sites, a project was undertaken by the Electrical Research Department to further study transient disturbances caused by the switching of specific equipment in selected industrial, commercial and residential environments. The project was requested by the Technical Services and Development Department of Program Support and Services Division, Energy Management Branch.

Measurements of transient disturbances were made at a residential site. However, because of problems experienced with the BMI 4800 Powerscope in the measurement of these transients, tests were never carried out at industrial or commercial sites. This report describes the characteristics of transients measured in one residential household and describes problems with the BMI 4800.

job	file	date	report no.
18-140-112	816.22	December 31, 1991	91-303-K

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

2.0 *Residential Transients*

In residential circuits, transient voltages originate from load switching transients and lightning transients [2,3]. Load switching transients can be associated with major power switching disturbances such as capacitor bank energization or the minor switching of household devices or appliances. Common household devices known to generate transients include refrigerators, furnaces, fluorescent lamps, pump motors, food mixers [2].

Lightning transients are high-energy surges that can result from either direct strikes to primary or secondary circuits, or induced voltages from the electromagnetic fields of nearby strikes. Limited data [2] indicates several lightning-caused surge occurrences above 3,000 volts with one reaching 5,600 volts. The frequency of lightning surges will be affected by local geographic and meterological conditions.

Transient overvoltages associated with the switching of capacitors are modest in comparison. Capacitor energization transients exhibit peak overswings of generally less than 2 pu [1], with a frequency of from 400 Hz to 4 kHz, decaying within a few milliseconds [4]. These are lower in frequency and longer in duration than the fast transients that occur during contact arcing in local switching of household loads.

The circuit opening by air-gap switches (relays and contactors) produces a succession of clearing and re-ignitions which generate bursts of fast ringing surges in the circuits being switched. The bursts of very fast surges associated with local load switching have very little energy but are capable of producing serious interference upset associated with the fast risetimes, to digital circuits which are fast enough to respond to these fast transients [5]. The IEC specifies an electrical fast transient (EFT) that is a standard test waveform consisting of bursts of impulses with 5 ns risetime and 50 ns duration [6].

Branch circuits and loads introduce resonances, reflections and absorptions that result in complex transient waveform characteristics. The amplitudes also depend on the specific installation and electrical conditions at switching [7].

3.0 *Instrumentation*

Transient measurements were made at a 120 V household outlet that feeds a freezer. Figure 1 shows the instrumentation and test setup used to compare the BMI 4800 Powerscope and the Nicolet 460 digital oscilloscope. The BMI and Nicolet were isolated from the ac supply to eliminate ground loops. A single ground was provided for the measurements at the measurement point.

The BMI samples impulses at 2 MHz with 7 bit resolution. A twisted shielded pair, approximately 20 m in length was connected to one input channel of the BMI. The shield ground wire was connected to the u-ground at the outlet at the measurement point and to the BMI chassis ground at the other end. Short jumpers from this channel were used for the other inputs for the different tests.

---

1 The per unit (pu) overvoltage is the peak value of the transient overswing, measured from the 60 Hz voltage zero, divided by the zero-to-peak value of the 60 Hz voltage.

The Nicolet has a sampling rate of 200 MHz with 8 bit resolution. The Tektronix Type P6009, 100x probe (standard 9 ft cable) was used for each of the 4 channels of the Nicolet 460. The ground clip for each probe was connected to the u-ground at the measurement point and the coaxial cable shields were connected through the BNC connectors at the input to the Nicolet chassis.

Figure 2 shows the setup for transient measurements using only the Nicolet. A specially-made trigger box was used to trigger all four channels on the Nicolet on an impulse of either polarity at a preset threshold. The probe had been properly compensated in this configuration, prior to the tests. Figure 3 shows the results. The risetime of the probe/trigger box/scope combination was measured as 10 to 15 nanoseconds.

4.0 Comparison Between BMI and Nicolet

There was considerable discrepancy between the transients recorded by the BMI and the Nicolet. The Nicolet was triggered using the trigger signal from pin 5, U22 on the BMI 4800 acquisition board to ensure that the instruments were capturing the same disturbance. Two examples of BMI records are given in Figures 4 and 5. The corresponding Nicolet records are shown in Figures 6 and 7.

In Figure 4, the BMI recorded a single pulse of greater than 800 volts with a risetime of 16 μs and a duration of perhaps 50 μs. The decaying part of the pulse looks more like the transient response of the BMI high-frequency filter rather than the actual shape of the transient. This is borne out by the corresponding record captured by the Nicolet shown in Figure 6. The transient is shown to be a burst of fast pulses lasting only about 9 μs, with a peak amplitude of 40 volts at most. The BMI reads 20 times higher than the Nicolet. Similar observations can be made between the BMI and Nicolet traces in Figures 5 and 7 except that the duration of the transient recorded by the BMI and Nicolet are similar because there is no overshoot in the BMI response. In this example, the BMI reads 30 times higher than the Nicolet.

The "uncalibrated data" warning on the BMI printout indicates that the calibration module had expired. However, this change in calibration status was very recent and similar results had already been obtained within the accepted calibration period during preliminary tests at another household.

Simultaneous measurements on two channels of the Nicolet compares the waveforms at the measurement point and the BMI input terminals to examine possible differences due to the length of the cable pair used to feed the BMI. Figure 8 shows the results. The upper trace shows the transient at the BMI terminals. The lower trace shows transient at the measurement point. The time delay of about 25 ns is consistent with the impulse propagation time over this length of cable. The almost doubling of the amplitude can be attributed to the reflection of the transient at the input terminals. The reflected pulse is seen as the second "bump" in the waveform at the measurement point. This difference is considerably less than the differences seen in the examples above where the BMI peak transient levels were recorded up to 30 times higher than the Nicolet.

5.0 Discrepancies Within the BMI

The four BMI input channels were connected in parallel to measure the same measurement point to check for inconsistencies between the different channels. In Figure 9, all four channels were set for the same threshold setting of 100 volts in the manual-range mode. In separate tests, a different threshold setting (75, 150, 225, and 300 volts) was set for each channel in manual-range (Figure 10) and in auto-range (Figure 11). With the exception of the location of the point-on-wave of the transient, the results can be seen to vary considerably. Both the amplitudes and waveshapes are inconsistent between the channels, depending on the settings of the BMI.

In Figure 9, with the same threshold in manual mode, the waveshapes for each channel were similar but the amplitudes varied between 140 and 241 volts. With different thresholds settings the variations between channels were larger. In manual range, the amplitudes varied from 241 to 686 volts and in auto range the amplitudes varied from > 200 volts to 762 volts. The corresponding Nicolet records in Figures 12, 13 and 14 for the different test conditions show bursts of fast pulses with peak amplitudes of just over 50 volts. In these results, the BMI read up to 15 times higher than the Nicolet.

Furthermore, preliminary tests in a different household, comparing the Nicolet 460 and a Tektronix 2440 digital oscilloscope against the BMI, showed similar responses on the digital scopes (about 30 volts, line-to-ground), while the BMI read more than 10 times higher (line-neutral), during the operation of a refrigerator. A laboratory comparison of the three instruments was performed using the Transient Interference Generator (TIG) which produces repetitive oscillatory transients with risetimes of about 25 nanoseconds [8]. The measured levels were similar on each instrument, suggesting that the BMI discrepancies were more likely due to radiated field effects rather than the result of anomalous responses to the conducted transient.

6.0 Evaluation of BMI Measurement Discrepancies

The discrepancies in test results between the BMI and the Nicolet, and the additional inconsistencies between each channel on the BMI lead to considerable uncertainty in the validity of the BMI results. The customer service and engineering departments at BMI were given the opportunity to explain these discrepancies but could not come up with an answer. They were unable to duplicate the conditions and results in their laboratory.

Some of the differences in waveform between channels might be attributed to the low sampling rate of the BMI compared to the fast risetimes and short duration of the transients indicated by the Nicolet measurements. The risetimes exceed the design parameters of the high-pass filter but we would expect attenuation of the fast transients which is not the case. The apparent amplification of the transients is puzzling. Possible explanations include ringing in the filter, or coupling into secondary circuits in the BMI where scaling may be improperly applied.

Another possibility is that pulse stretching due to instrument bandlimiting may result in the overlapping of the closely-spaced individual pulses, producing a response that is the result of the addition of several pulses. Impulse repetition rates of up to 8 MHz are evident in the examples of Figures 6 and 7.

The anomalous results also may be due to electromagnetic coupling of the transients, either into the instrument leads or directly into the BMI. The electric fields generated by the operation of the freezer, measured at the location of the BMI, ranged from 40 ω 95 V/m using an IFI Model EFS-3 field strength meter (wide band meter from 10 kHz to 200 MHz). However, the BMI did not trigger during the operation of the freezer with the input leads disconnected and either floating, or tied to the u-ground of the outlet at the measurement point.

On the other hand, earlier laboratory tests [1] indicated that the BMI is susceptible to high fields generated by high-powered walkie-talkies. Therefore, additional radiated tests were performed in the laboratory by exposing the BMI and Nicolet to radiated transient fields from a Tesla generator and the fields leaked from the TIG output leads without direct connection to the instrument input terminals. Triggering was inconsistent on both instruments but the BMI was far more susceptible to false triggering due to radiated fields from either source. On one occasion, when both appeared to

trigger simultaneously, the BMI recorded a 203 volt transient while the Nicolet recorded an 8 volt transient.

The results of the field and laboratory tests to explain the discrepancies in the BMI measurements are unclear. Nevertheless, the uncertainty in the BMI results makes it difficult to have confidence in the BMI 4800 impulse measurements in an environment were there may be fast transients or high electromagnetic transient fields. Further investigation is required to resolve the nature and cause of the problem.

8.0 Nicolet Transient Measurements

There is far less uncertainty in the Nicolet measurements. The analog bandwidth and sampling rate give adequate frequency response and time resolution for the fast transients. The probe was properly adjusted and calibrated to give a response of about 10 to 15 nanoseconds, using a pulse generator in the laboratory.

The scope was isolated through an isolation transformer and grounded through the shield of the probe lead at the measurement point. This reduces the measurement difficulties introduced by different ground references at high frequencies in the measurement system. The different ground potentials cause circulating ground currents to be pumped into the cable shields and into the instrument. A test for the severity of this problem is to short the probe to its own ground. Figure 15 shows the result of one measurement. On the grounded channel, the magnitude of the recorded transient is about 2 volts peak-to-peak. This level is less than 5% of the transient levels measured line-to-ground and neutral-to-ground and, therefore, introduces very little error in the measurements. Measurement of the line-to-neutral transients can be produced by subtracting the line-to-ground and neutral-to-ground records digitally, during post-processing on the Nicolet.

9.0 Summary of Nicolet Test Results

Transients were captured during the switching operation of a freezer and electric furnace. Figure 16 shows the transients generated when the freezer switches on and off. These transients are characterized as short bursts of fast pulses lasting less than 15 μs. The individual pulses shown in the expanded traces of Figures 17 and 18 have risetimes that are less than the 10 to 15 ns risetime limitation imposed by the measurement system. Figure 19 shows an electric furnace transient. The transient is a voltage notch associated with the voltage drop during the initial current surge when the furnace turns on. The risetime of about 0.5 μs is much slower than the transients associated with the switching of the freezer.

During a 4 1/2 hour period of unattended recording, 22 transients were captured using a trigger level of 50 volts. The peak voltage levels of the captured line-to-neutral transients were fairly evenly distributed between 50 and 118 volts. All the transients where essentially bursts of impulses lasting from 1 to 22 μs, consisting of individual impulses with risetimes of 20 ns or less. Figure 20 shows some of the variations in the waveshapes of the recorded transients. Expanded traces in Figures 21-23 show more of the details. The individual impulses also exhibit oscillatory responses of about 1 to 1.5 MHz.

10.0 Conclusions

- Residential transients associated with the local switching of common household equipment including a freezer and electric furnace were recorded.

- The captured transients were all less than 120 volts in amplitude, line-to-neutral.

- The furnace transient was essentially a unipolar notch with a 0.5 μs risetime.

- Fast transients were generated by the operation of the freezer. These are characterized as bursts of impulses lasting up to about 20 μs with individual impulse risetimes of 20 ns or less. The individual pulses are closely spaced, with repetition rates of up to 8 MHz. Individual impulses exhibited oscillatory responses of about 1 to 1.5 MHz.

- The measurement of fast transients typical of a residential environment is outside the capabilities of the BMI 4800 Powerscope which has a 2 MHz sampling resolution and a risetime limitation of 1 μs.

- Test results showed wide discrepancies between the BMI records and the Nicolet records as well as inconsistencies within individual channels of the BMI. On simultaneously captured disturbances, the BMI produced records with transient levels up to 30 times higher than the Nicolet. The inconsistencies within the BMI channels varied with threshold levels and whether the BMI was set for manual-range or auto-range.

- It is unclear whether the problems with the BMI are due to anomalous response to the conducted transients at the input terminals or to susceptibility to radiated transient fields.

- The uncertainty in the BMI performance suggests that results of measurements in an environment where there may be fast transients or high electromagnetic transient fields should be used with discretion.

- The use of long lead lengths can result in a doubling of impulse amplitudes due to the reflection of the impulse caused by the impedance mismatch at the input of the BMI. The use of short leads, preferably the manufacturer supplied leads, is recommended for transient measurements.

11.0 Acknowledgements

I wish to thank Bruno Pietrantonio for his excellent work in performing the measurements and data analysis.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

G.K. Hatanaka
Research Engineer
System Studies Section

GKH:am

References

[1] G.K. Hatanaka. Power Quality Measurement Survey-Industrial. Ontario Hydro Research Division Report no. 91-163-K, June 27, 1991.

[2] Francois D. Martzloff and Gerald J. Hahn. Surge Voltages in Residential and Industrial Power Circuits. *IEEE Transactions on Power Apparatus and Systems*, Vol PAS 89, No 6, July/August 1970.

[3] Ronald B. Standler. Transients on the Mains in a Residential Environment. *IEEE Transactions on Electromagnetic Compatibility*, Vol 31, No 2, May 1989.

[4] E.P. Dick. Review of Capacitor Switching Effects on Power Quality. Ontario Hydro Research Division Report no. 88-239-K. October 11, 1988.

[5] Revision to C62.41, Draft 7 - January 1990. *IEEE Recommended Protection Surge Voltages in Low-Voltage AC Power Circuits.*

[6] IEC 801-4, *Electromagnetic compatibility for industrial-process measurement and control equipment. Part 4: Electrical fast transient/burst requirements.*

[7] E. Keith Howell. How Switches Produce Electrical Noise. *IEEE Transactions on Electromagnetic Compatibility*, Vol EMC-21, No 3, August 1979.

[8] Ontario Hydro Standard Specification A-28M-82, *Oscillatory Transient Interference Immunity Test.*

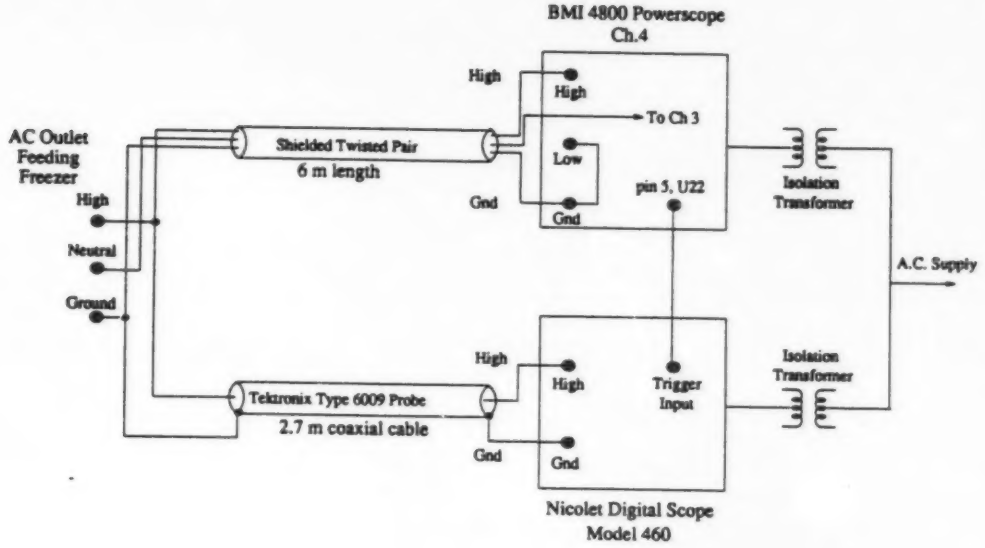

Figure 1 Instrumentation Setup for Comparison of BMI and Nicolet

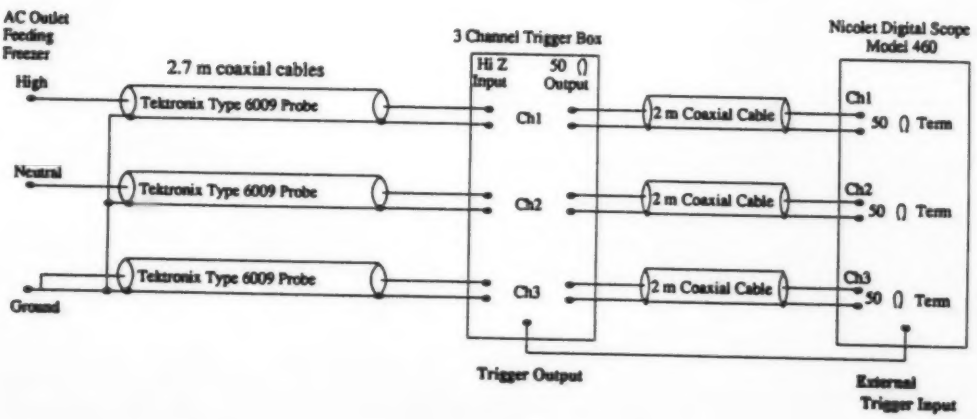

Figure 2 Instrumentation for Transient Measurements

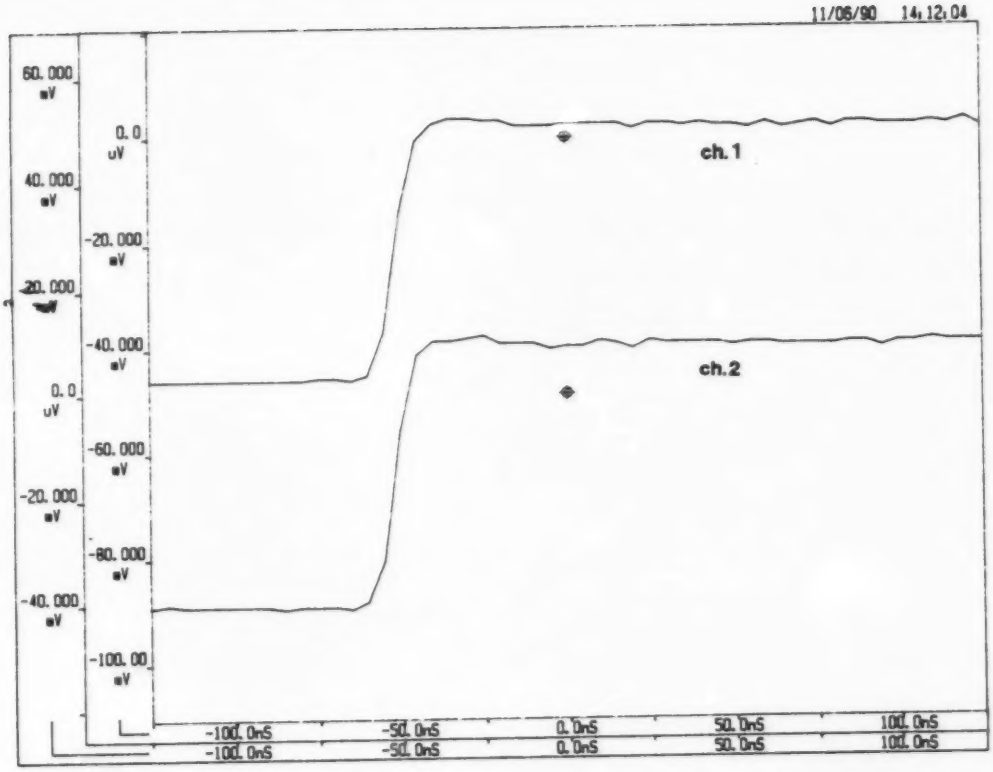

Figure 3 **Compensation of Tektronix P6009 Scope Probe Feeding Nicolet 460 Oscilloscope Through External Trigger Box**

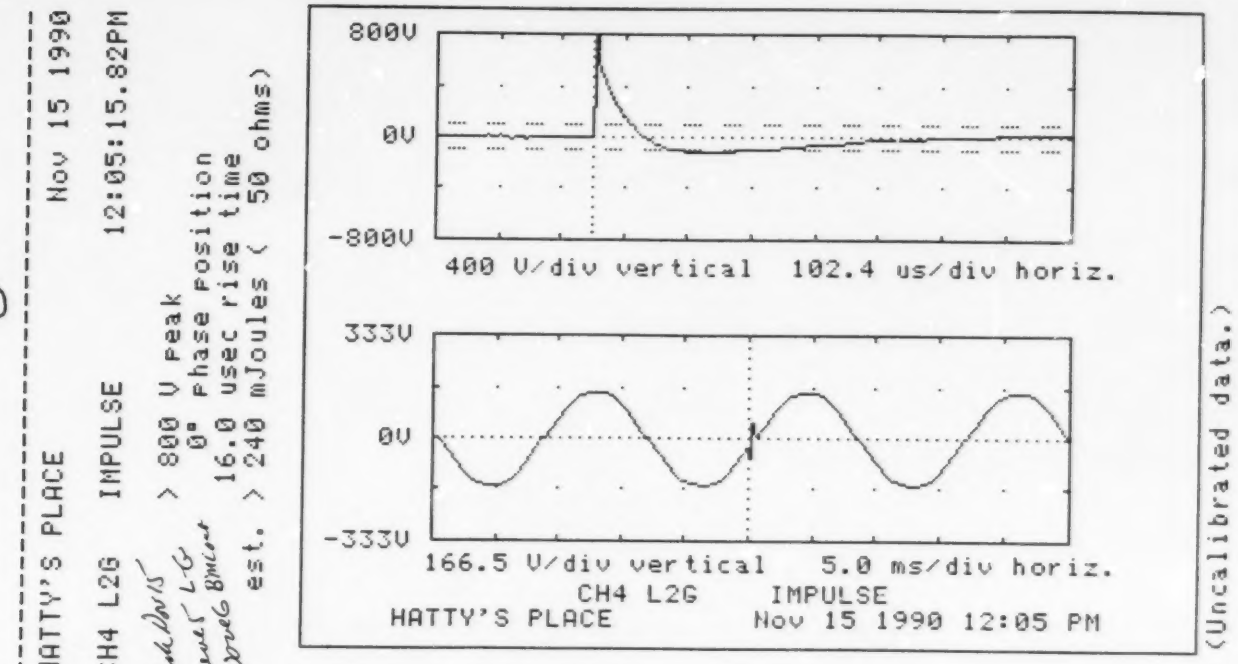

Figure 4 Transient Recorded by BMI 4800 - Example A

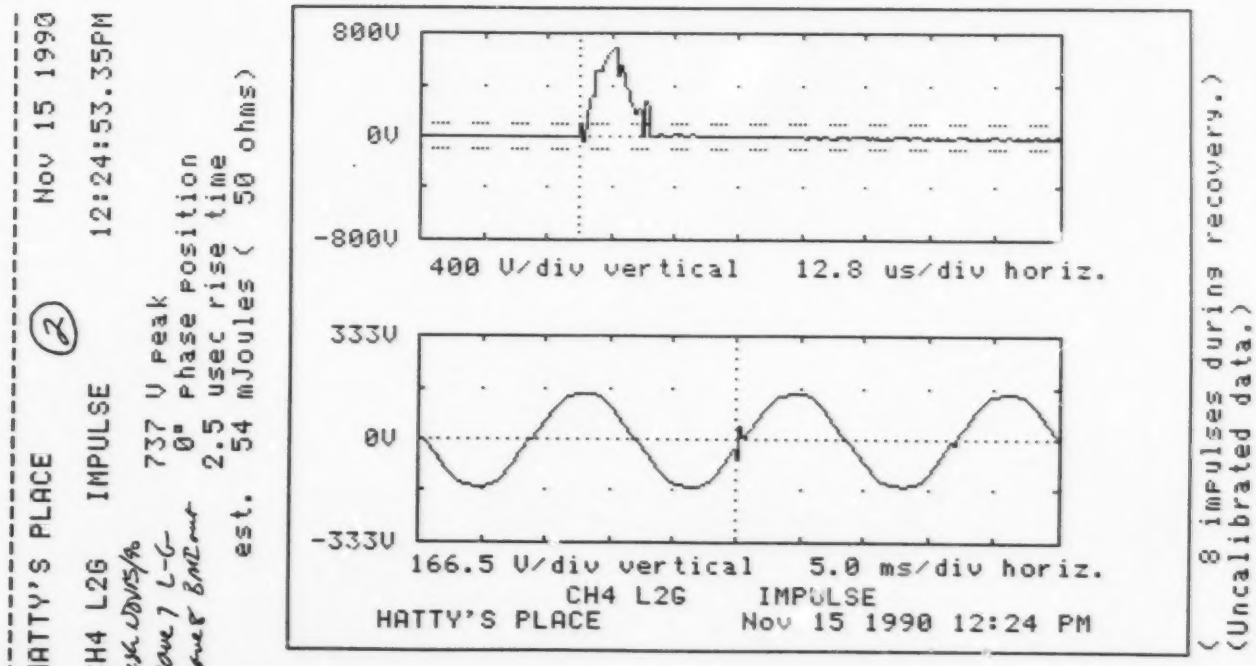

Figure 5 Transient Recorded by BMI 4800 - Example B

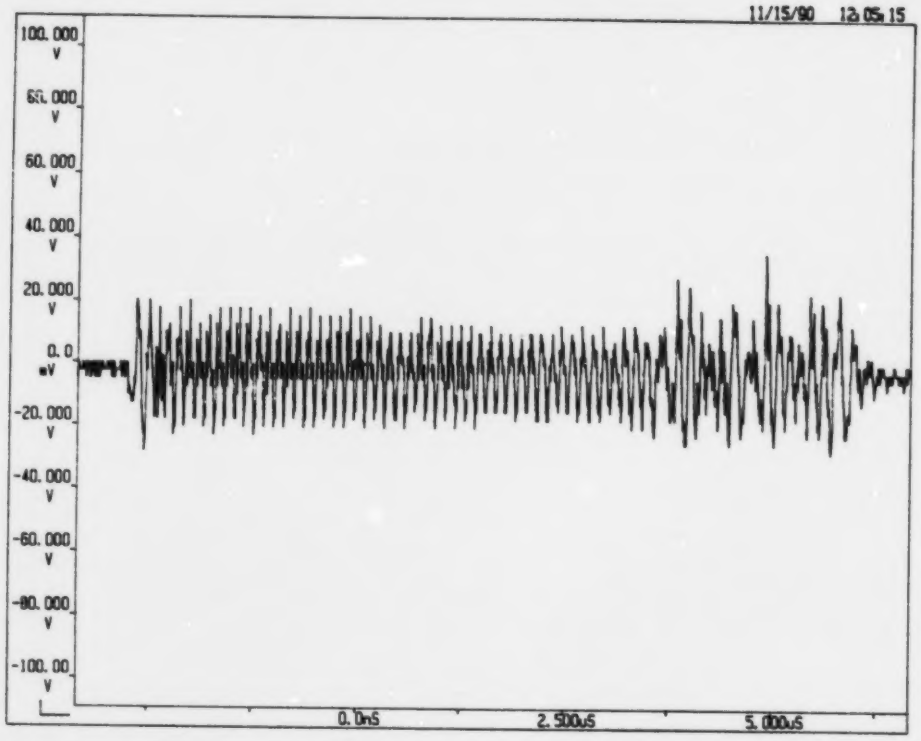

Figure 6 **Transient Recorded by Nicolet 460 - Corresponds to BMI Record in Figure 4**

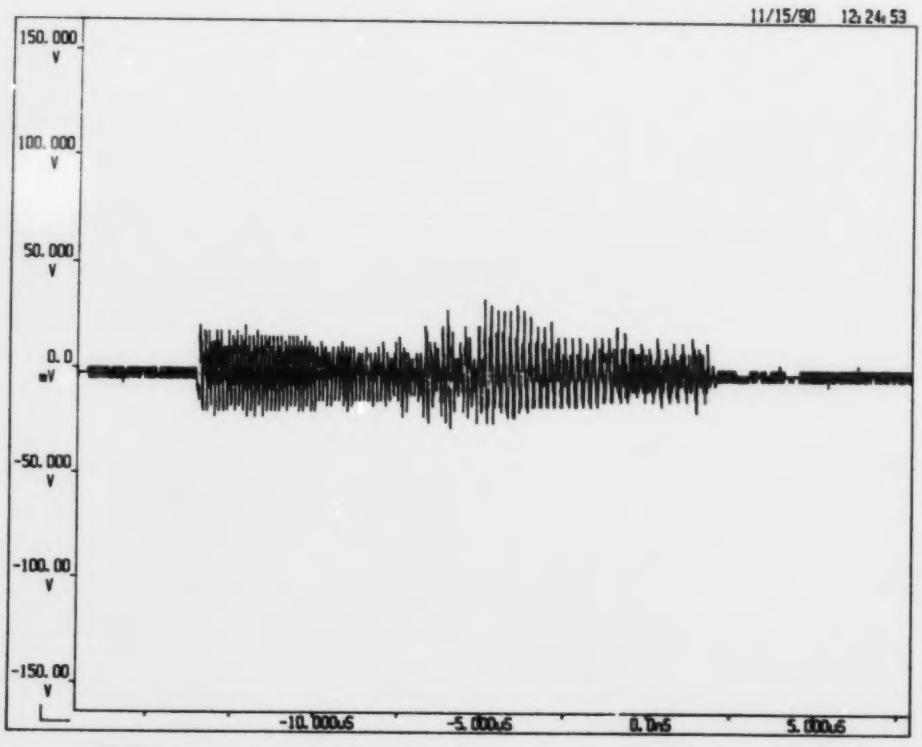

Figure 7 **Transient Recorded by Nicolet 460 - Corresponds to BMI Record in Figure 5**

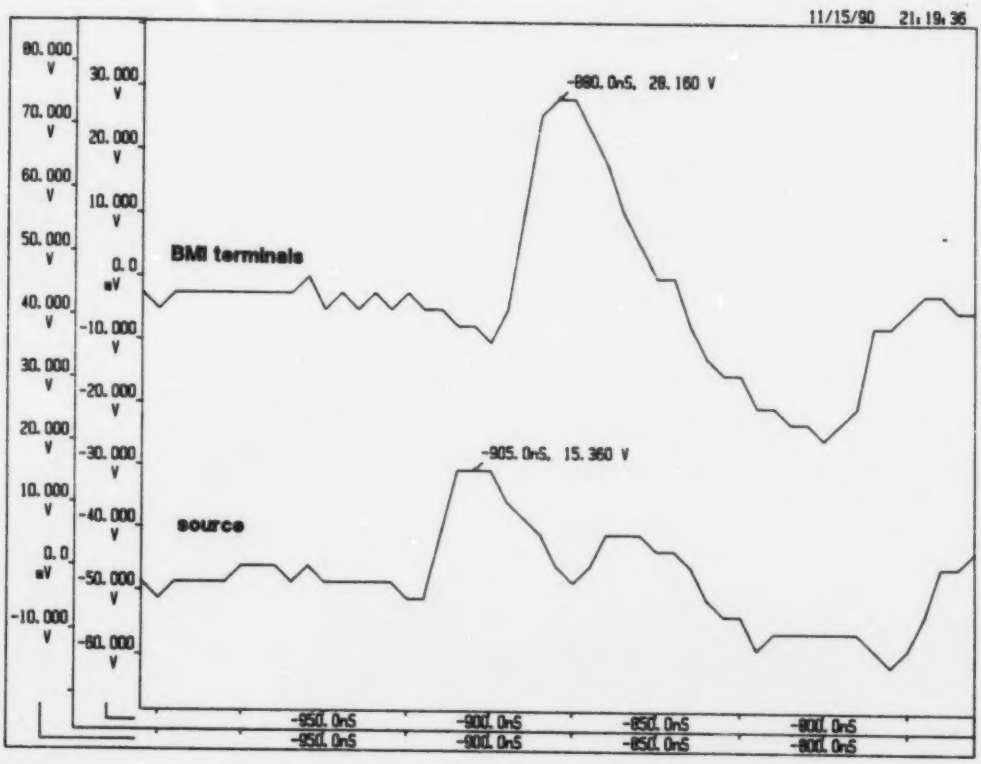

Figure 8 **Transient Records at the Source End and the BMI-Input End of a 6 m Instrumentation Lead**

Figure 9 BMI Response on All Channels to Same Transient - Manual Range; 100 Volt Threshold

Figure 10 BMI Response on All Channels to Same Transient - Manual Range; Ch1 = 75V, Ch2 = 150 V, Ch3 = 225 V, Ch4 = 300 V Thresholds

Figure 11 BMI Response on All Channels to Same Transient - Auto Range; Ch1 = 75 V, Ch2 = 150 V, Ch3 = 225 V, Ch4 = 300 V Thresholds

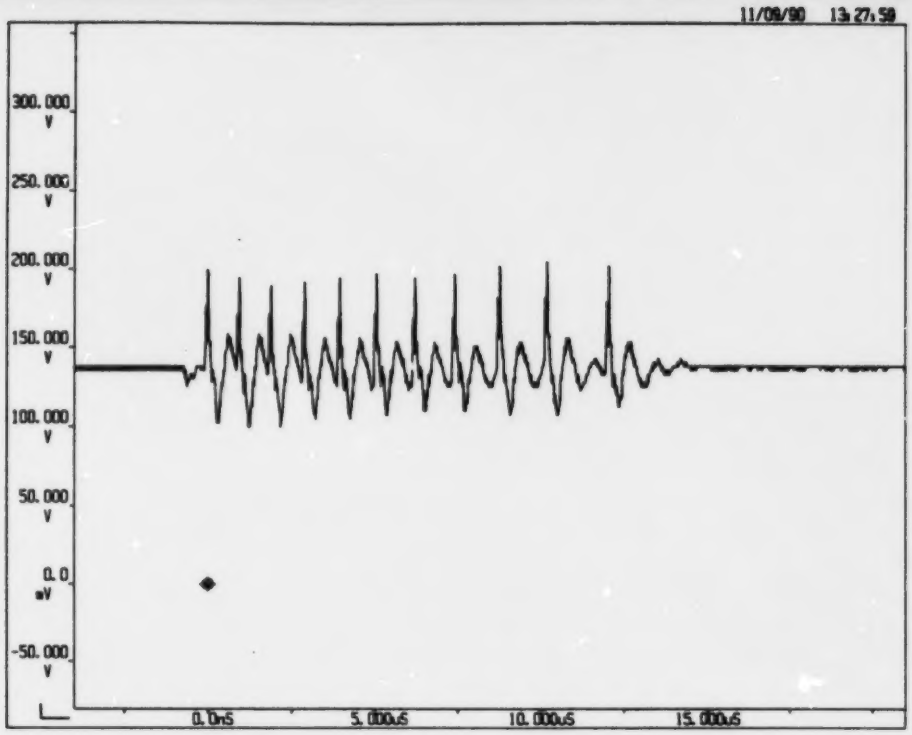

Figure 12 Nicolet Response to Same Transient as BMI in Figure 9

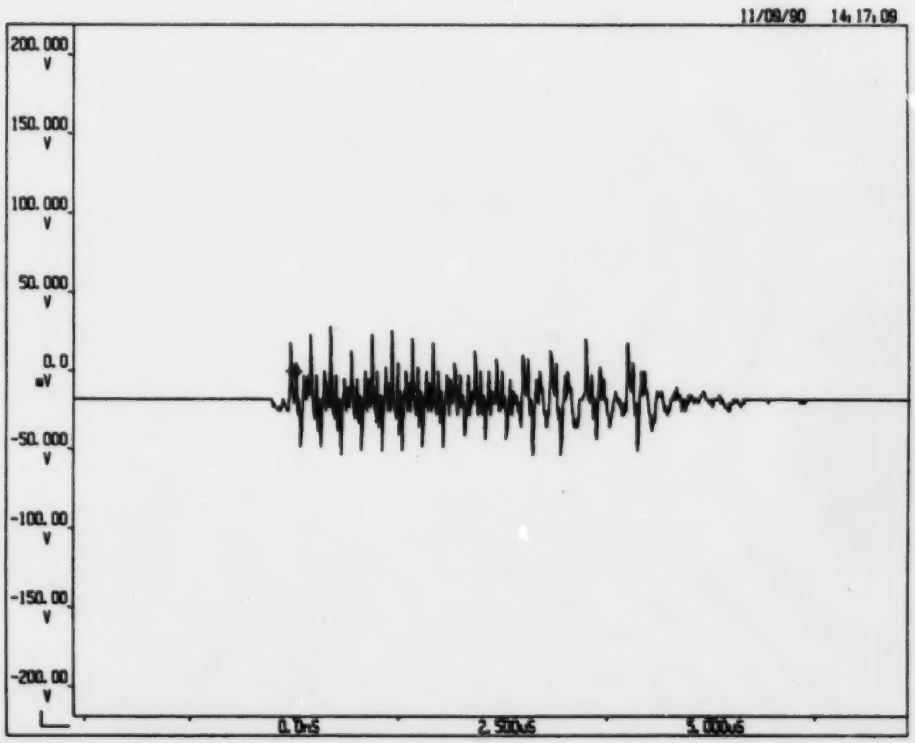

Figure 13 Nicolet Response to Same Transient as BMI in Figure 10

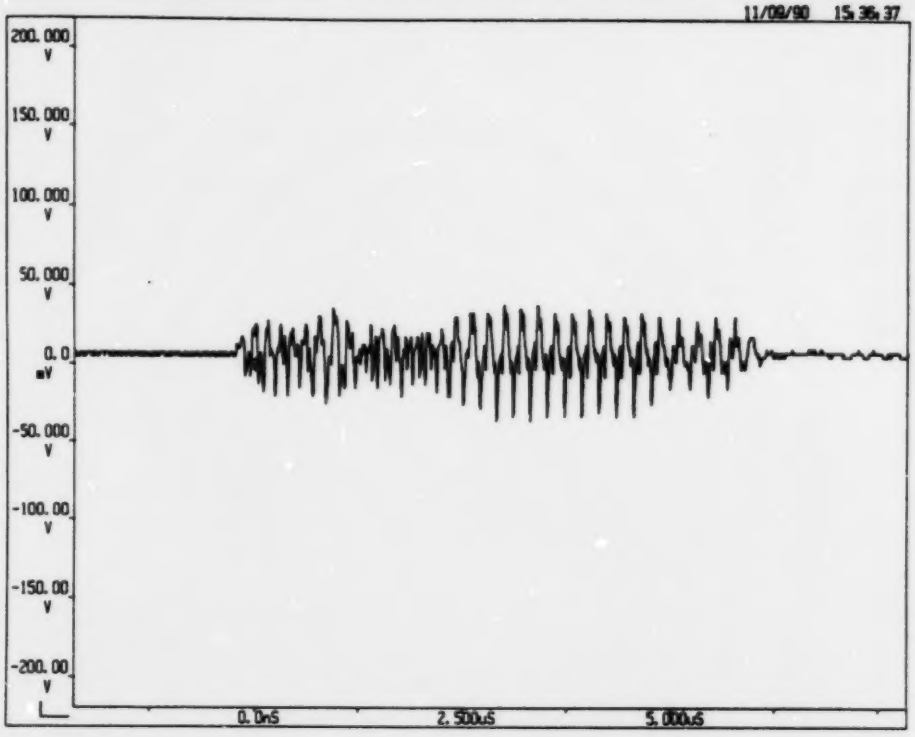

Figure 14 Nicolet Response to Same Transient as BMI in Figure 11

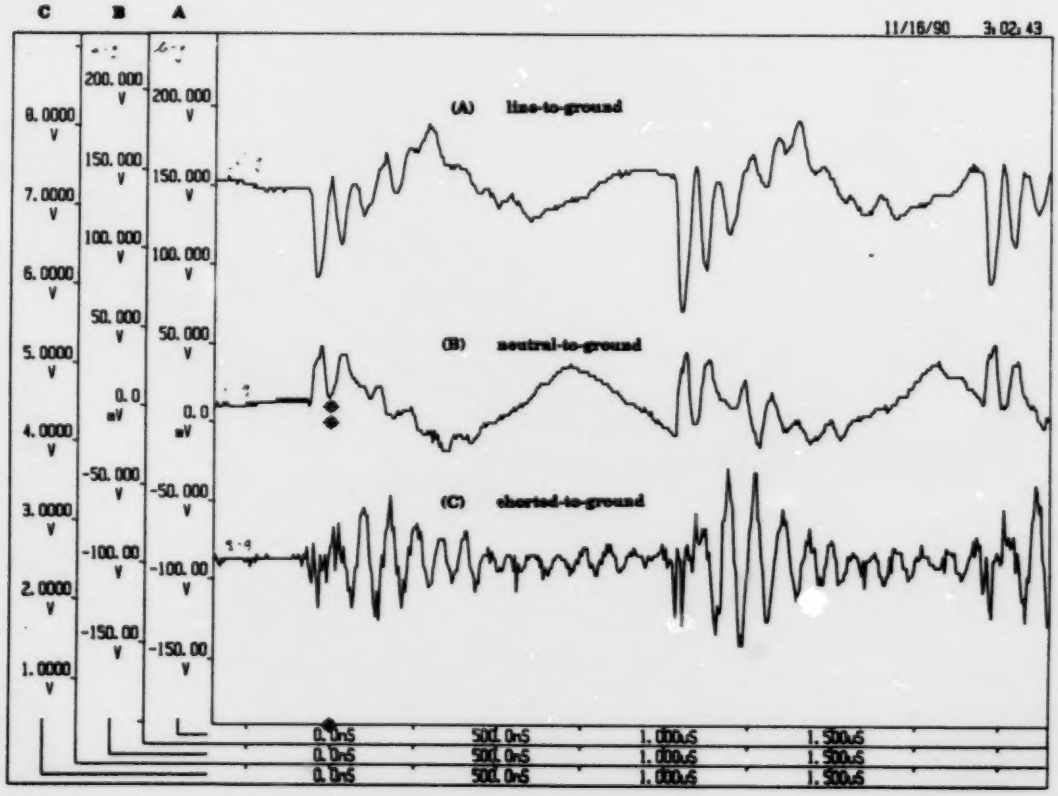

Figure 15 Response of Nicolet With Probe Tip Connected to Measurement Ground Point

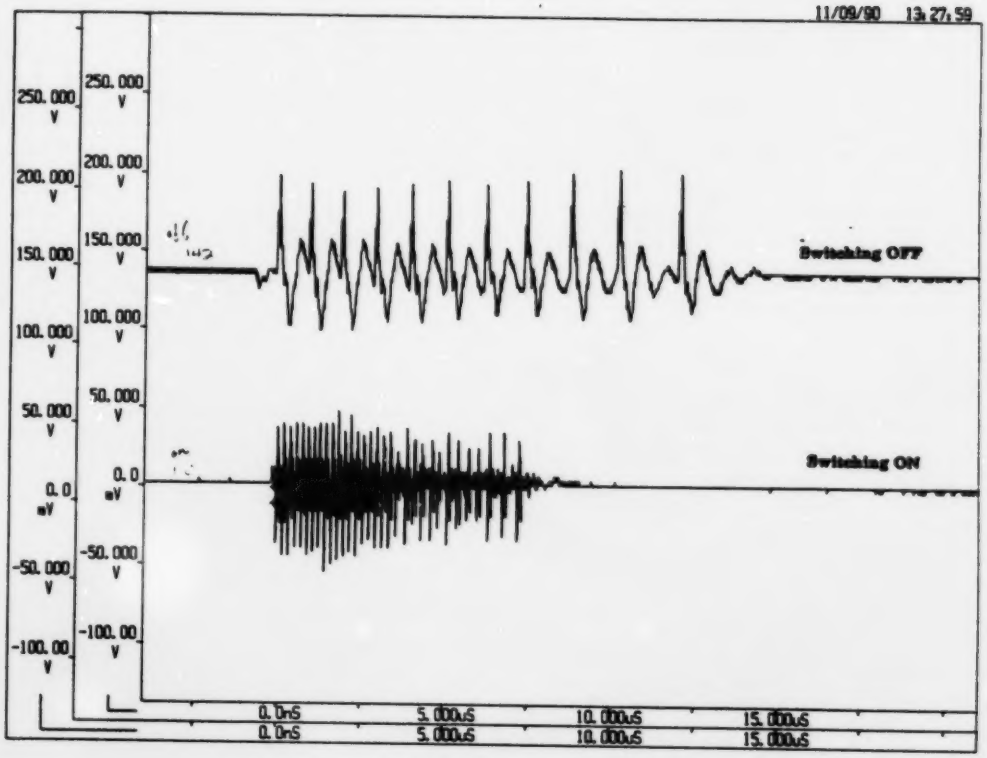

Figure 16 Transients During Switching Operation of Freezer

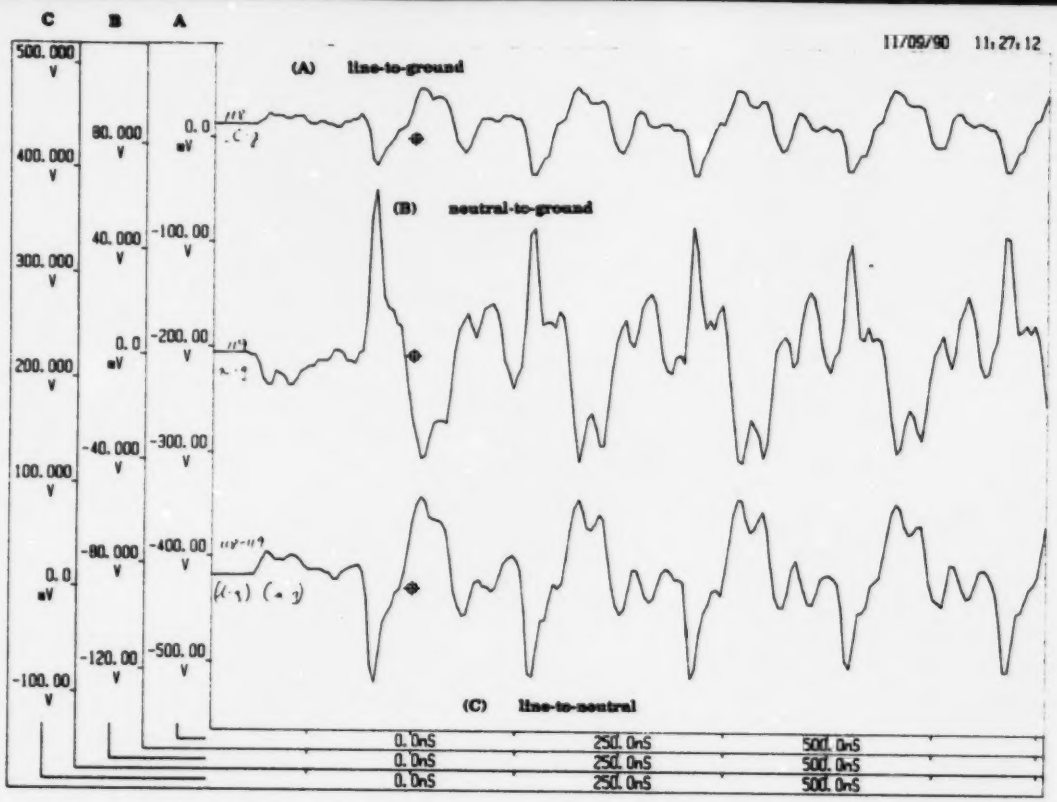

Figure 17 Expanded Record of Transient During the Switching-On of a Freezer

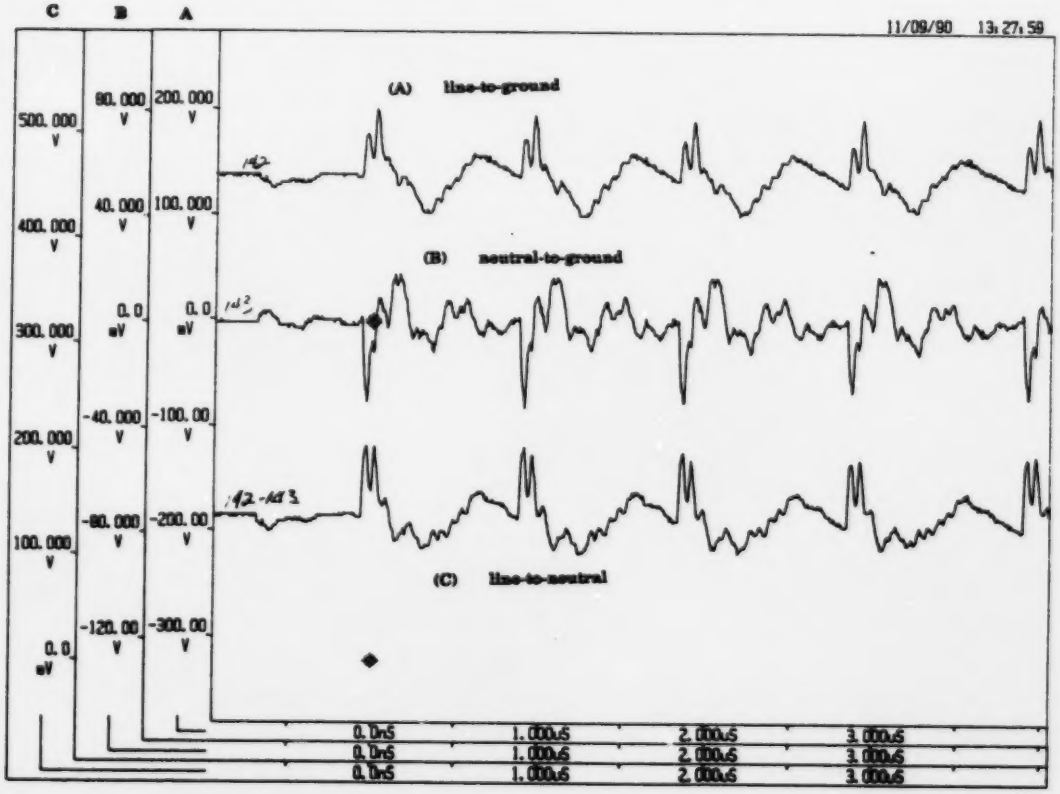

Figure 18 Expanded Record of Transient During the Switching-Off of a Freezer

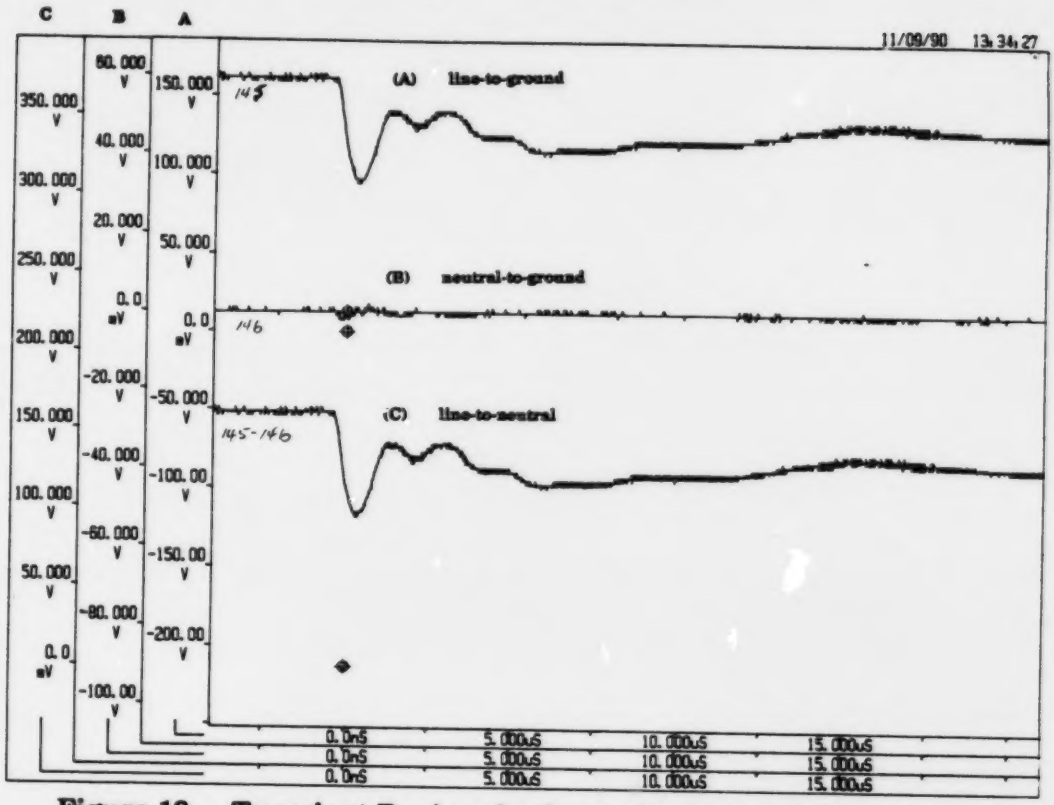

Figure 19 Transient During the Operation of an Electric Furnace

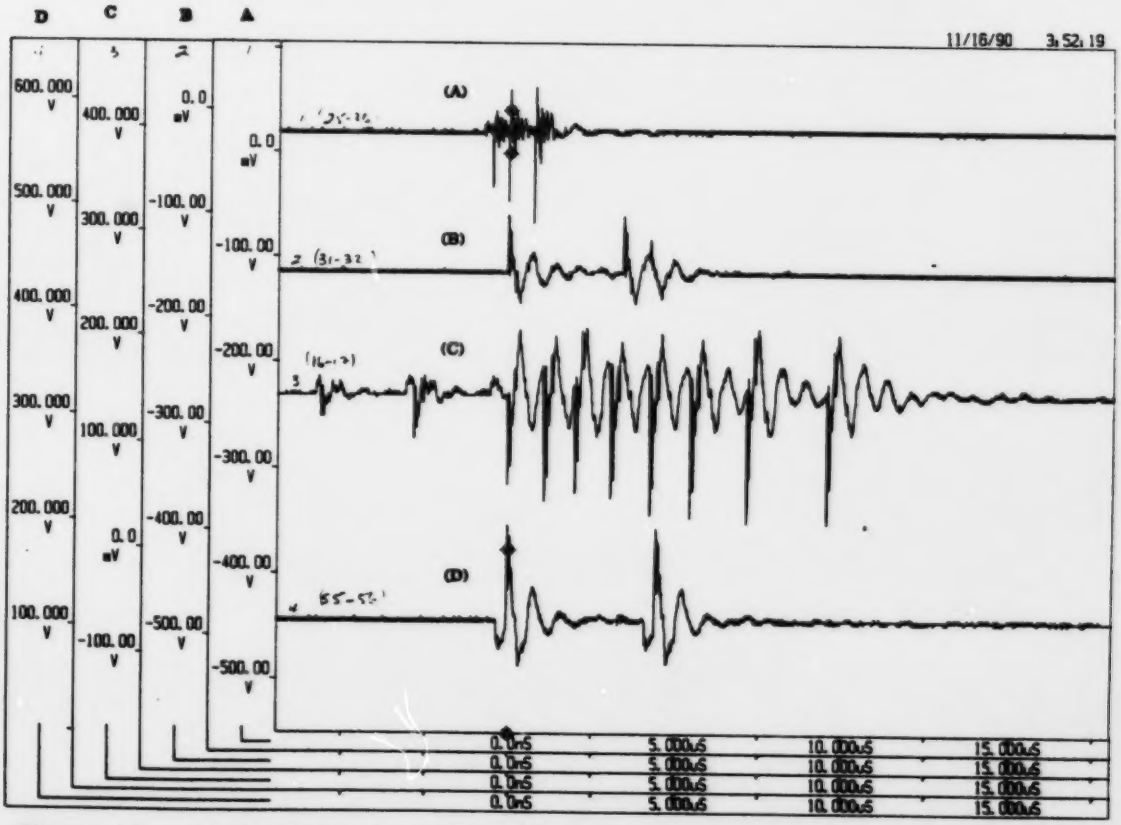

Figure 20 Typical Fast Transients Captured in a Residential Environment

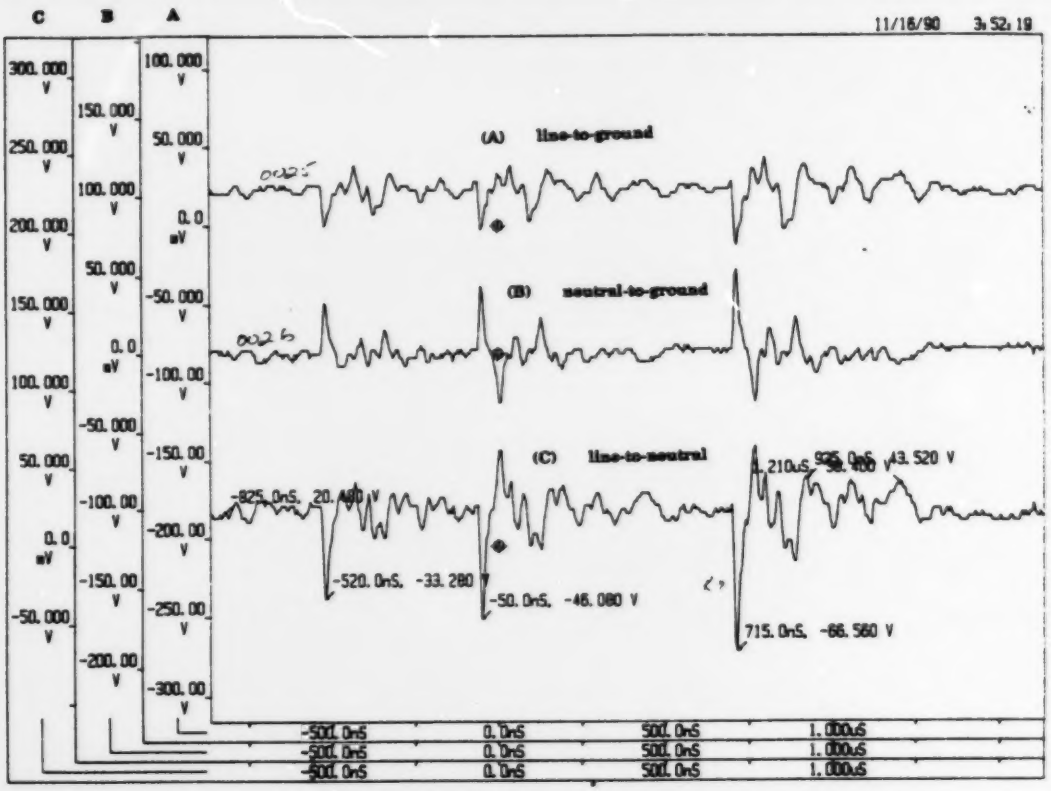

Figure 21 Expanded Record of Transient in Figure 20 (A)

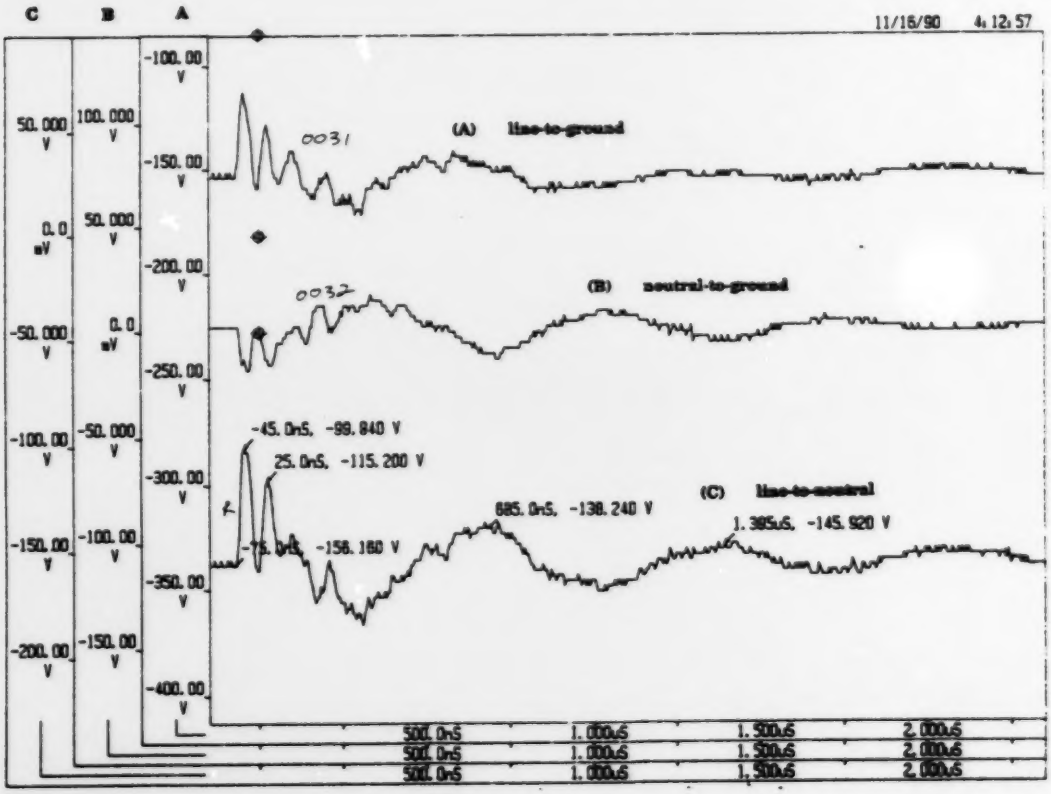

Figure 22 Expanded Record of Transient in Figure 20 (B)

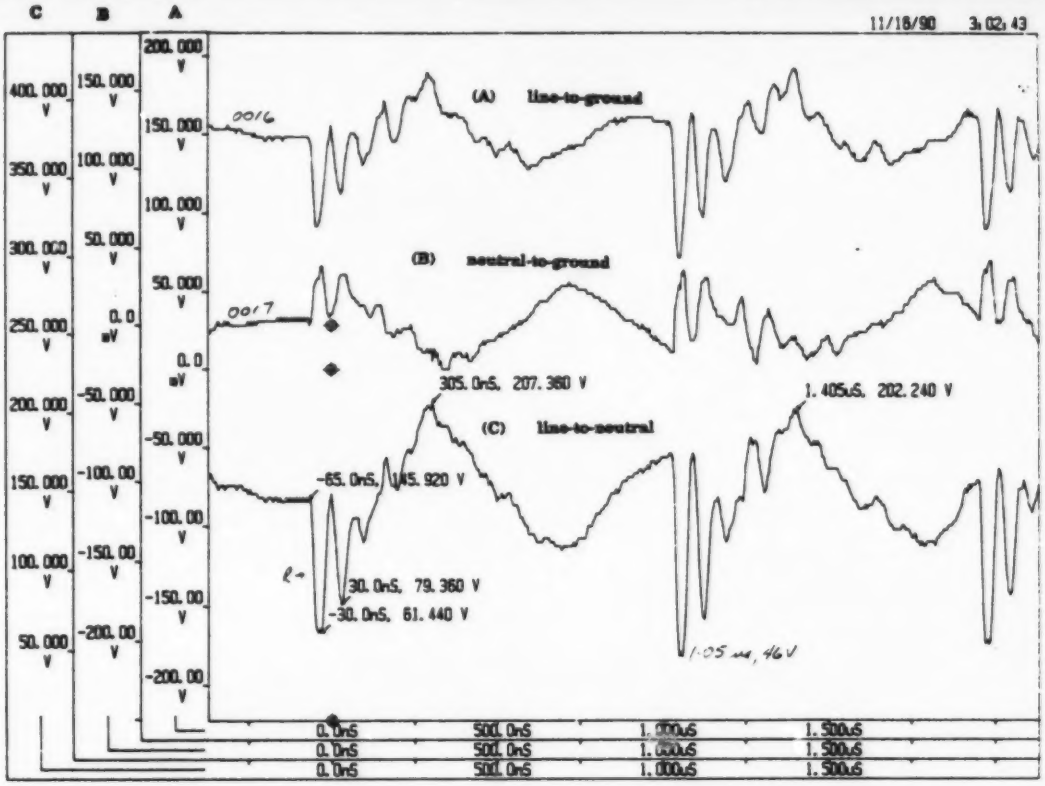

Figure 23 Expanded Record of Transient in Figure 20 (C)

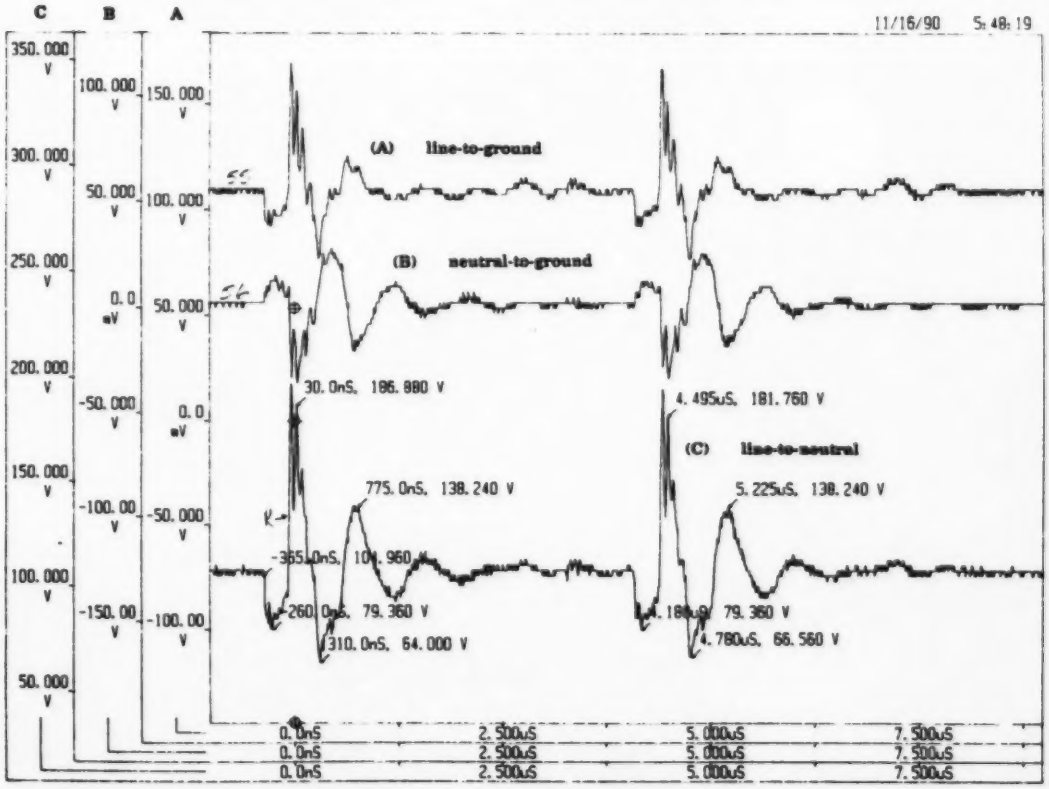

Figure 24 Expanded Record of Transient in Figure 20 (D)